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## Review

## Modified perceptual training in sport: A new classification framework

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## ABSTRACT

**Objectives:** To overview a framework that provides a theoretically-grounded approach to predicting the types of modified perceptual training tasks that will stimulate transfer of improved perceptual skills to sport performance environments. Modified perceptual training (MPT) collectively describes on- or off-field sports training tasks that are specifically designed to develop visual and perceptual-cognitive skill. Traditional training approaches in sport include sports vision training and perceptual-cognitive training, while recently, new technologies have enabled a broad range of additional MPT tools to become available to coaches and athletes.

**Design:** Short literature review and opinion article.

**Methods:** Literature in the fields of sports vision training and perceptual-cognitive training are summarised and contrasted. A selection of emerging MPT technologies are then overviewed. This leads to the identification of three interacting factors of MPT task design that may influence the task's capacity to transfer improved training performance to actual competition: (i) the targeted perceptual function, (ii) stimulus correspondence, and (iii) response correspondence, which are assimilated with key tenets of representative learning design.

**Results:** These three theoretically-grounded differences are adopted to support and justify the structure of the Modified Perceptual Training Framework which sets out predictions for future research to test in order to clarify the transfer effect of MPT tools.

**Conclusions:** The application of the Modified Perceptual Training Framework may assist in future testing, design and selection of beneficial training tools in sport and as such, is predicted to have significant impact in empirical and practical settings.

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## 1. Introduction

To support performance, elite athletes require a combination of general visual skills (e.g. visual acuity, contrast sensitivity, depth perception)<sup>1,2</sup> and performance-relevant perceptual-cognitive skills (e.g. anticipation, decision-making).<sup>3</sup> While these skills are typically developed as a consequence of regular, on-field practice, training techniques are available that can enhance those skills outside of, or in conjunction with, regular training. Perceptual training has commonly included sports vision training (SVT) that uses generic stimuli (e.g. shapes, patterns) optometry-based tasks with the aim of developing visual skills,<sup>4,5</sup> or perceptual-cognitive train-

ing (PCT), that traditionally uses sport-specific film or images to develop perceptual-cognitive skills.<sup>6,7</sup> While these traditional formats involve their own specific training tasks, when compared against each other, they present two considerably different training approaches; these task design differences (i.e. targeted perceptual function, training stimuli, training response mode) will be detailed in later sections. Improvements in technology<sup>5–7</sup> have also led to the development of additional tools (e.g. reaction time trainers, computer-based vision training, and virtual reality systems) which claim to enhance perceptual skill using a variety of different equipment in on- and off-field settings that don't necessarily fit in to these existing categories. This observation is due to these emerging approaches using task design factor combinations that differ from both the specific SVT and PCT approaches. That is, while these emerging tools aim to develop specific perceptual skills that may also be trained using SVT or PCT (i.e.

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visual through to perceptual-cognitive), the specific training stimuli and/or training response mode used in training, as well as the training environment in some cases, may differ. To cover this variety of techniques, *modified perceptual training* (MPT) collectively describes on- or off-field tasks that are specifically designed to improve an athlete's perceptual skill. To help establish the value of these MPT tools, this paper proposes a new framework that provides testable hypotheses for future research to clarify the degree to which each could improve performance. We do so by classifying these emerging (and existing) approaches according to a number of key differentiating factors specifically related to the design of MPT tools.

The presumed usefulness of any MPT tool relies on three key assumptions.<sup>4,8</sup> First, the targeted skill should discriminate between athletes of different skill levels. Second, improvements in the skill of interest should be possible through training, and third, any improvement in that skill should transfer to enhanced on-field performance. While meeting the third assumption is undoubtedly the most critical in an applied sense, empirical evidence for the first two assumptions should be considered for all MPT tools. For the first two assumptions, inconsistent empirical support, particularly regarding visual skill in athletes, theoretically undermines the applicability of the third assumption.<sup>9</sup> However, many MPT tools claim to address the third assumption of improved on-field performance, yet investigations of transfer are rare (for an exemplar transfer investigation see Gabbett, Rubinoff<sup>10</sup>). Ideally, transfer tests should provide dynamic, goal-directed tasks that sample the complex perceptual information available within competitive sport contexts that supports functional, sport-specific perceptual and/or physical skill-based performance; that is, transfer tests should be representative of a competition scenario.<sup>11,12</sup> To achieve this representation, suitable transfer tests should be 'field-based' in nature, permitting interaction with 'live' competition elements, such as teammates or opponents, achievable in laboratory, simulation and actual performance contexts (e.g. within training and competition settings or scenarios, or performance statistics taken from such contexts).<sup>13</sup> The strongest empirical evidence for the utility of MPT tools in sport (i.e. evidence for assumption three) may come from existing or future studies incorporating such tests, at minimum, following an MPT intervention, but also ideally as a pre-test in order to assess the inter- and intra-group differences (i.e. training versus placebo and/or control) in transfer test performance stimulated by the MPT intervention. A framework for MPT in sport would provide testable predictions for assessment in future research regarding the design and type of MPT tasks that improve on-field performance more effectively as established through robust study designs incorporating representative transfer tests.

The aim of this paper is to outline a framework that provides a theoretically-grounded approach to predicting the degree to which a MPT approach will improve on-field performance. The paper will firstly review and summarise SVT and PCT approaches before introducing emerging MPT tools and approaches. From this, three overarching differences in MPT design will be identified (i.e. targeted perceptual function, stimulus correspondence and response correspondence). Second, these differences in MPT approaches will be assimilated with principles (i.e. the role of perceptual processes in linking performance-relevant information and action) from representative learning design (RLD),<sup>11</sup> a theory commonly applied in the design of effective field-based skill practice tasks. Finally, principles from RLD will then be adopted to assist in setting-up and discussing the theoretical premise for the new three design factor continua-based framework, before considering the framework's impact in empirical and applied settings.

## 2. Modified perceptual training: a traditional dichotomy and emerging approaches

### 2.1. Sports vision training

Traditionally, MPT has been classified as either SVT or PCT, generating a dichotomy of training approaches. Here, SVT incorporates any task drawn from optometric training programmes, commonly used for the remediation of visual problems, but in this context applied to athletes.<sup>4</sup> Sports vision training targets the visual functioning of the eye (e.g. the lens, extraocular muscles) through to the visual cortex and association area of the occipital lobe.<sup>2</sup> In sport, this pathway facilitates vision to optimise the quality of the athlete's visual experience and their moment-to-moment perceptual representations of their environment. SVT operates on the premise that improving the athlete's vision will lead to improvements in competitive performance.<sup>2</sup> While common characteristics such as static and dynamic acuity, and contrast sensitivity are said to be fundamental to elite sport performance,<sup>1</sup> additional skills also linked to sport performance include depth perception, ocular tracking and peripheral sensitivity.<sup>2</sup> These skills may interact to assist the athlete in the detection and identification of visual stimuli (e.g. localizing a tennis ball during its trajectory), discrimination (e.g. separating the tennis ball from a yellow cap worn by a crowd member) and tracking (e.g. following a moving projectile).

A defining feature of SVT is the consistent use of generic stimuli (e.g. alphanumeric symbols, shapes, patterns or colours),<sup>2,14</sup> although the tasks chosen may be tailored depending on the visual demands of the sport or scenario. For example, in interceptive sports such as baseball and cricket where the batter must hit an approaching ball, vergence exercises may be prioritised because developing this skill may assist in sustaining accurate alignment of the eyes on the approaching ball. Further, performing (or responding in) SVT typically involves simple ocular responses, for example, changes to the shape of the lens or ocular muscle contraction/relaxation. In some instances, this is coupled with non-specific manual gestures or manipulations (e.g. finger pointing or using the hands to adjust the training equipment), though this is generally rare. Table 1 provides a summary of common SVT approaches.

Intervention studies using SVT have demonstrated improvements in visual skills as a result of training in sports such as field hockey<sup>14</sup> and tennis,<sup>15</sup> which equates only to evidence for their trainability (i.e. the second assumption). These studies used a combination of generic stimuli tasks taken from optometry approaches (e.g. hart charts, marsden ball, brock string) as well as light-boards or computer-based programs (e.g. D2 Dynavision, Vision Performance Enhancement Program), requiring simple ocular responses or non-specific manual gestures as responses. The targeted visual skills in these studies were pre- and post-tested on either the same task used to train them and/or alternative generic stimuli and response tasks, while no transfer test was used to establish any transfer to improved field hockey or tennis performance.<sup>14,15</sup> Meanwhile, in their 4-group study design (two different SVT tools, placebo and control), Abernethy and Wood<sup>4</sup> demonstrated non-group dependent improvements in select visual skills, but failed to find significant improvement for any group in their transfer test consisting of an on-court tennis forehand drive transfer test that required participants to hit a projected tennis ball accurately towards a specified target zone. These results suggests the third assumption of transfer has not been met and highlights the lack of evidence for using SVT tools to improve performance.

The inconsistent or lack of evidence for the transfer of improved visual skills has been attributed to: training which targets skills that might not limit performance (i.e. voiding the first assumption, and the third by default), improvements as a result of task familiarity

**Table 1**

A summary of key design aspects of MPT approaches and exemplar tools, considering the targeted perceptual skill(s), stimuli characteristics and response modes.

MPT category/format	Sub-category	Exemplar tool(s)	Targeted perceptual skill(s)	Stimuli		Response mode(s)
				Visual characteristics	Behavioural characteristics	
Sports vision training		Snellen Chart Marsden Ball	Depth perception Static visual acuity, ocular tracking	Alpha-numeric symbols, patterns, generic shapes/objects (e.g. beads, rope, balls, tubes) constituting training equipment	Printed or projected as charts on neutral surfaces (moving or stationary), objects/equipment behave under physical manipulations	Ocular adjustments, simple manual ges- tures/manipulations
		Landolt-C Brock String	Dynamic visual acuity Vergence, accommodation			
		Howard-Dolman Apparatus	Depth perception			
Perceptual-cognitive training	Video-/image- based	Uses television, computer or image projection technology	Anticipation Decision-making Pattern recognition Situational probability Visual attention	Film or photography-based images of sport scenarios – capturing field of play, teammates, opponents Images can be 2D or 3D, from first or third person perspectives	Structured, sport-specific patterns of movement	Verbal or written reports Button/key press (non-specific action or gestures) Simulated sport actions
	Interactive	Virtual Reality <sup>21</sup> (non-immersive and immersive tools)	Higher-order perceptual-cognitive skills (anticipation, decision-making)	2D or 3D computer-generated or manipulated sport environments (playing surfaces, teammates, opponents)	Structured, sport-specific patterns of movement	Natural skill execution
	Field-based	Stroboscopic glasses <sup>22</sup> Occlusion goggles/equipment <sup>23</sup> Modified (marked/coloured) equipment <sup>39</sup> QE Training <sup>38,40</sup> Video-based perceptual modelling/instruction <sup>41</sup>	QE, anticipation, decision-making (high-order perceptual cognitive skills, likely incorporates supporting mid- and low-order perceptual skills)	Natural training environment (playing surfaces, teammates, opponents, equipment)	Natural and structured, sport-specific patterns of movement	Natural skill execution
Computer-based tools (or 'apps' on hand-held devices)		Ultimeyes <sup>42</sup> Sanet Vision Integrator <sup>43</sup> Senaptec Sensory Station <sup>44</sup> Vizual Edge Performance Trainer <sup>45</sup> EyeGym <sup>46</sup>	Various low-order visual-perceptual skills	Alpha-numeric symbols, generic shapes and patterns	Unpredictable flashing (appear- ance/disappearance) patterns and illumination locations, random or no movement on neutral background	Ocular adjustments, simplistic manual screen tapping or swiping gestures
				Digitally-produced sport-based stimuli (e.g. balls)		
Touch- board/- screen tools		Wayne Saccadic Fixator <sup>47</sup> Dynavision D2 <sup>48</sup> Sports Vision Trainer <sup>49</sup> Vision Coach <sup>50</sup> AcuVision 1000	Various low-to-mid order perceptual-cognitive skills (particularly peripheral sensitivity, recognition, hand-eye coordination)	Small LED lights	Fixed on, or set-in, a board or screen (commonly checkerboard style), pre-programmable or randomised illumination sequencing, proactive or reactive settings for light deactivation	Non-specific reach-and-touch gestures

LED lighting equipment	Batak Pro <sup>51</sup> FITLIGHT Trainer <sup>52</sup>	Eye-hand/-foot coordination	LED lights mounted on plastic discs	Fixed (to a frame) or portable (individual) arrangements of discs, pre-programmable or randomised illumination sequencing, proactive or reactive settings for light deactivation	Non-specific reach-and-touch/-kick gestures
Minimal/simplified essential performance information (computer, TV or projection viewed tools)	NeuroTracker <sup>53</sup>	Mid-order perceptual-cognitive skills (general visual attention, awareness, working memory) Pattern Recognition, Anticipation	Series of digitally-produced yellow 3D spheres (targets and distractors) Series of light points	Random movement and interaction (collisions) inside black volumetric virtual cube	Verbal report or computer mouse-click selection of target spheres
	Point-light Display <sup>54,55</sup>			Structured, sport-specific patterns of <i>relative</i> movement on black (or neutral) background	Verbal report or keyboard button press

Quiet eye (QE); light emitting diode (LED); two-dimensional (2D); three-dimensional (3D).

rather than genuine learning (e.g. testing on the same task used for training), training tasks that isolate and develop a singular skill that may actually interact in conjunction with other skills through complex perceptual processes to contribute to elite sport performance, and a lack of double-blinded, placebo-controlled, field-based transfer designs.<sup>4</sup> These issues make it difficult to resolve the possible effect of SVT on competitive performance.

## 2.2. Perceptual-cognitive training

Perceptual-cognitive training aims to improve an athlete's ability to make use of sport-specific visual information to enhance on-field performance through the facilitation of skills such as anticipation and decision-making. The PCT approach targets higher-order networks of perceptual-cognitive functioning, particularly the complex interactions between regions of the cerebral cortex, cerebellum and brain stem involved in the selection and, in some cases, control of movement.<sup>16</sup> In sport, these pathways support the athlete's perceptual-cognitive skills that enable the rapid interpretation (understanding) of the current sport environment, and integrates this with their sport-specific knowledge to facilitate successful skill performance.<sup>17</sup> Decision-making and anticipation (i.e. the ability to accurately predict future events based on advanced information), are the skills most commonly investigated and enhanced in PCT research.<sup>6</sup> These skills may also be supported by other perceptual-cognitive skills targetable in PCT such as pattern recognition,<sup>18</sup> the pick-up of contextual and situational probability information,<sup>19</sup> and the modification of visual search and attentional strategies towards meaningful regions of the sporting environment.<sup>20</sup> Perceptual-cognitive training operates on the premise that by targeting sport-specific perceptual-cognitive skills, an improved ability to interpret, integrate and use task-relevant stimuli will lead to improvements in performance. Traditionally, PCT involves projection or computer/television screen presentation of sport-specific scenarios (e.g. still images or video), exposing the participant to stimuli typically seen during competition (e.g. simulated teammates, opponents, balls, playing surfaces).<sup>6,7</sup> During or after the sport-specific film has been presented the participant is generally required to express a decision or anticipatory response based on the training scenario presented to them. Perceptual-cognitive training may require the athlete to respond in a variety of formats, from writing to performing a simulated or natural sport-specific action. Technology developments have now enabled the emergence of PCT tasks that use alternative methods of presenting or manipulating sport-specific stimuli, such as immersive/virtual reality platforms<sup>21</sup> or field-based approaches.<sup>22,23</sup> In these PCT formats, the decision or anticipatory response is generally coupled with a simulated or natural sport-specific action; the suite of PCT tasks are summarised in Table 1.

In seeking to establish how PCT may be best implemented, research paradigms have considered instructional techniques,<sup>24</sup> occlusion and manipulated viewing conditions,<sup>10</sup> colour cueing/highlighting,<sup>25</sup> anxiety-inducing conditions,<sup>26</sup> practice schedule design<sup>27</sup> and video playback manipulation in a variety of invasive team sports,<sup>28</sup> interceptive sports<sup>10,26,27</sup> and individual sports.<sup>29</sup> Despite this variety, findings consistently demonstrate improved perceptual-cognitive skill as a result of training (i.e. assumption two).<sup>3</sup> Researchers have also successfully demonstrated transfer of these improved skills using transfer tests (in laboratory and/or field-based settings) in their studies (i.e. assumption three).<sup>10,30,31</sup> In their training-control group study design, Hopwood et al.<sup>30</sup> used a 6-week cricket-specific video-based (fielder's perspective) PCT intervention targeting fielding anticipation in an attempt to improve movement initiation time (proxy measure for decision-making time) and fielding success. In the transfer test, participants stood in the field and were required

to intercept balls hit by a live batsman. Only the PCT group significantly improved fielding success pre- to post-test, while no differences were found for movement initiation time within or between groups between testing occasions.<sup>30</sup> In field hockey, Williams et al.<sup>31</sup> used an individualised 45 min video-based (goalkeeper's perspective) PCT intervention to train goalkeeping anticipation performance against penalty flicks as measured by decision time and response accuracy (a placebo group, who were provided a 45 min goalkeeping skills instructional video, and a non-training control group were also used). In the transfer test, live attackers and an actual hockey goal were brought in to the laboratory and the participants had to defend penalty flicks executed by the live attacker. Only the PCT group improved decision time pre- to post-test, while no other within or between group differences were found for response accuracy across testing occasions.<sup>31</sup>

However, occasionally video-based PCT research: (i) lacks representative transfer tests (i.e. computer-based sport-specific tests used only), (ii) uses assessments that isolate the perceptual-cognitive skill (i.e. assessing the skill in the absence of a sport-based context or void of (uncoupled from) sport-based movement responses) or, (iii) fails to provide evidence of the assessment task's reliability (i.e. statistical consistency of a given participants test-retest performance), discriminative validity (i.e. evidence for sport performance level-based differences in test performance) or accuracy of measurement methods (e.g. Portus and Farrow<sup>32</sup>).<sup>6,9</sup> Until research clearly demonstrates the types of PCT tasks and conditions under which transfer is facilitated, through the specifics of intervention study design and the use of representative transfer tests, the full utility of PCT for improving performance remains unclear.

## 2.3. Emerging MPT approaches in sport

Advances in technology have prompted growth in the variety of MPT equipment and programs available for use in sport. Table 1 summarises a selection of emerging MPT approaches and tools. It is important to highlight that these emerging MPT tools do not always precisely replicate the same combination of the three differences in MPT design (i.e. targeted perceptual function, training stimuli and training response mode, as detailed in Table 1) as observed in the SVT and video-/image-based PCT approaches, nor are the tasks always presented in the same conditions or environments. Further, some tools that may be used in sport are based on the adoption of theoretical constructs from (neuro)psychological research that discuss the development of general perceptual skills using generic tasks to improve context-specific functional performance. While there is a body of quantitative research using some of these emerging MPT approaches, the volume and quality of research and its reporting are areas for future research to address to definitively establish the utility of these approaches in sport.

For example, the electronic application program 'Ultimeyes', which adopts neuropsychological principles of neuroplasticity,<sup>33</sup> has been used in a training-control group study to demonstrate a decrease in strike-outs and an increase in runs-created measured as statistics from competition (i.e. a representative transfer test) in trained university baseball players.<sup>34</sup> Further, tools for stroboscopic training, which aims to enhance visual stimuli sensitivity by interrupting the natural flow of visual information,<sup>35</sup> have begun to permeate the MPT market. For example, stroboscopic glasses have been used during on-ice training tasks to train professional ice hockey forward and defence players in shooting and long pass accuracy, as measured in position-specific on-ice (i.e. representative) tests.<sup>22</sup> In the training-control group study (each group contained athletes of both playing positions) only the stroboscopic training group demonstrated significant pre- to post-test performance improvements across the on-ice tests.<sup>22</sup> Additionally, the 'NeuroTracker' computer program, which adopts the visual



attention paradigm of multiple object tracking,<sup>36</sup> has been used to train university soccer players in decision-making performance for passing, dribbling and shooting, as measured in field-based small sided games (i.e. a representative transfer test) that were subjectively assessed by qualified coaches on a simplistic good-poor decision coding instrument.<sup>37</sup> In the training-active control group study (active control viewed 3D soccer match videos) only the NeuroTracker-training group significantly improved passing decision performance pre- to post-test, while no other differences were found for either group on shooting or dribbling performance.<sup>37</sup> Further, a quiet eye (attentional control paradigm; QE) training protocol has been used with international-level skeet shooters, with overall shooting performance changes assessed via combining scores from three competitions (i.e. transfer test) prior to and following the QE training intervention.<sup>38</sup> In the training-control group study only the QE trained group demonstrated significantly improved pre- to post-intervention improvements in competition scores.<sup>38</sup> While these examples provide preliminary evidence that emerging MPT approaches may improve various perceptual skills that transfer to improved sport performance, further well-designed training studies are required to be conducted with all new and existing tools to develop a convincing body of evidence. Otherwise, if left under-investigated, claims of performance improvements from using some MPT tools will remain primarily anecdotal. There appears to be a significant opportunity for researchers to investigate the capacity of emerging MPT tools to train various perceptual skills and transfer this to improved competitive performance.

#### 2.4. Summary

A large suite of MPT tools and approaches now exist which claim to improve perceptual skill. Despite this variety, these approaches consistently differ across three factors. First, the perceptual function targeted by the training lies on a continuum between low-order visual skill and high-order perceptual-cognitive skill. Second, the stimuli differ between generic and sport-specific forms. Third, the required response varies between simple ocular responses and actual skill execution. To establish how these three factors might influence transfer, the following section introduces a new framework to better understand these approaches to perceptual training.

### 3. Modified perceptual training in sport: a new framework

Establishing a framework that provides testable predictions about which MPT approaches are likely to be most effective in improving sport performance, as evidenced through the use of representative transfer tests, is critical. This would enable researchers to assess and establish the comparative effectiveness of various MPT approaches for use in sport, using a theoretically grounded framework, before applying research findings to guide practitioners and coaches in the implementation of MPT with athletes. This section proposes the Modified Perceptual Training Framework (MPTF), which has been developed based on the adoption of key principles from representative learning design (RLD), and sets out a series of key predictions (testable hypotheses) regarding the effectiveness of MPT in sport.

#### 3.1. Representative learning design in sport: a summary and a link

The theoretical framework of RLD has been advocated for designing and assessing field-based practice tasks in sport.<sup>11,56</sup> However, links between key principles of RLD and the factors differentiating MPT formats are also evident. For training benefits

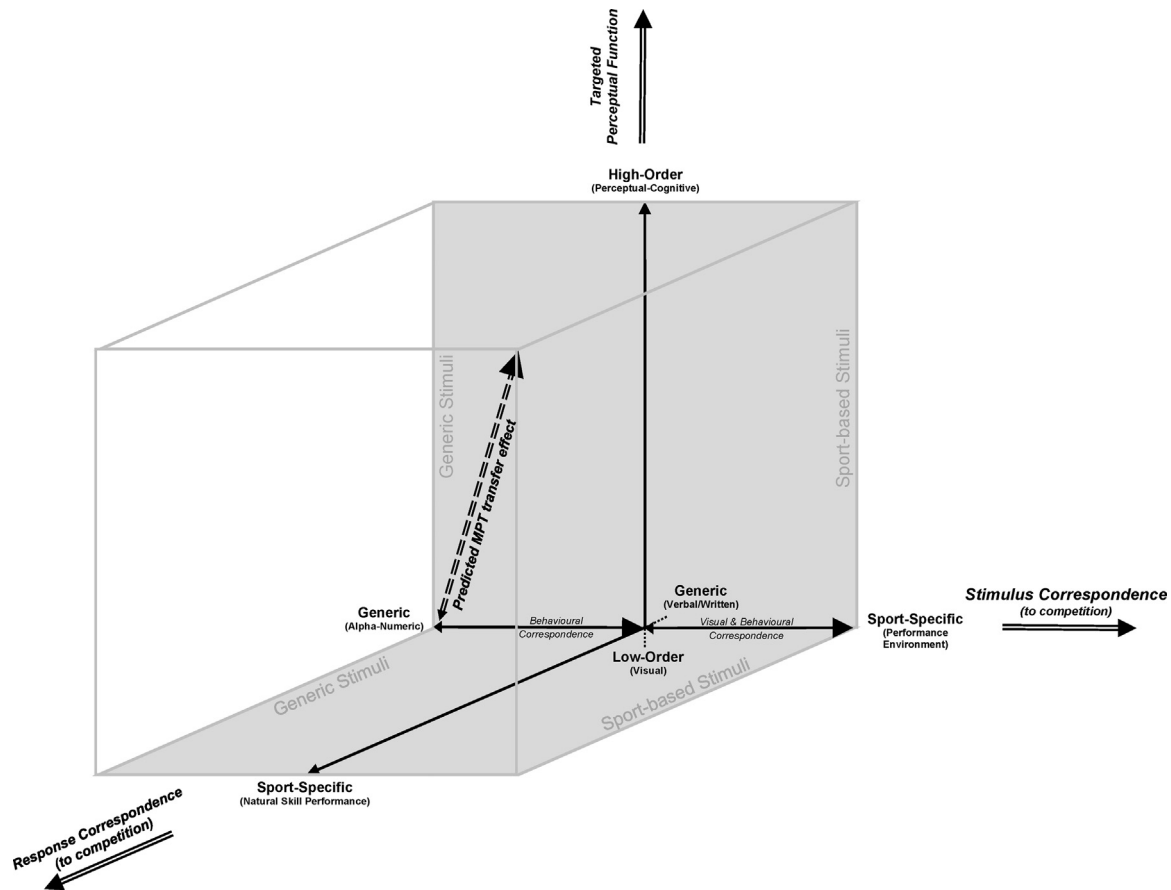
to transfer to competitive performance, RLD posits that training should *represent* competition. In application, RLD emphasises that, for skill practice to be most effective, tasks should accurately recreate performance-relevant information sources that athletes perceive and use to support movement coordination.<sup>11</sup> By coupling functional information with a physical response, an athlete's skill performance in training should better *transfer* to competition.<sup>13</sup> In other words, transfer is more likely to occur if an athlete practices sport-specific skills based on the perception of sport-specific information. Therefore, RLD highlights three interacting factors important for the design of effective practice tasks; (1) *perceptual processes* that link, (2) *information* to (3) *action*, which align with the three identified factors that differentiate MPT tools (1) *targeted perceptual function*, (2) *stimuli* and (3) *response mode*, respectively. This provides a theoretical underpinning for a MPT framework which seeks to make predictions about the perceptual skill transfer effect of using an MPT approach.

#### 3.2. The Modified Perceptual Training Framework (MPTF)

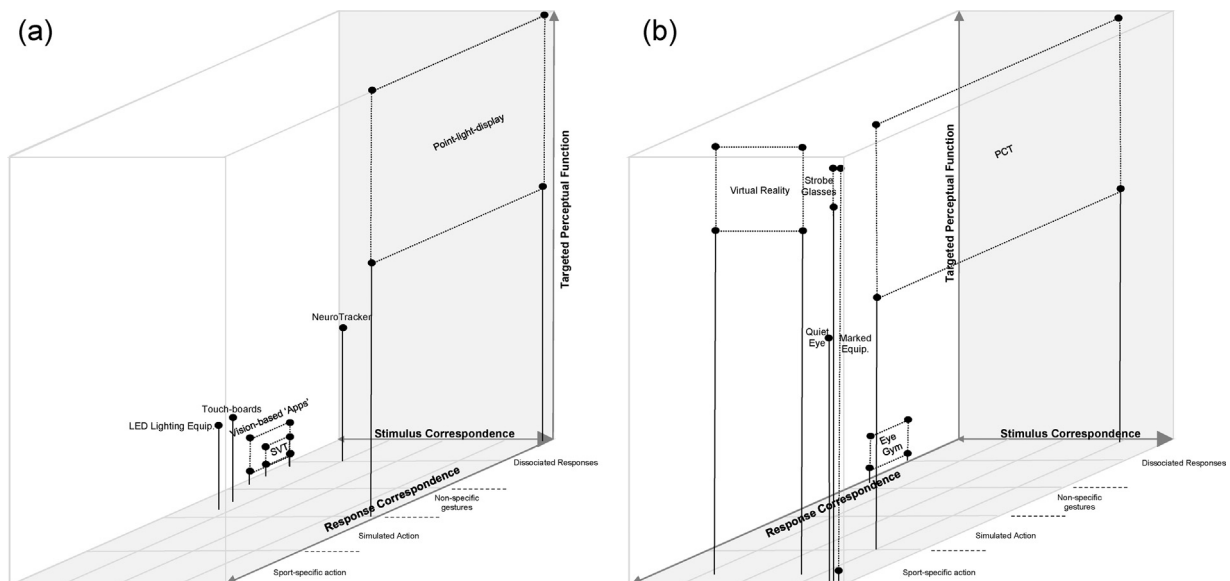
The MPTF (Fig. 1) provides a structured series of predictions regarding the effectiveness of MPT tools in sport for future research to empirically address. Each axis of the MPTF is a continuum capturing the three key differentiating factors of MPT and reflects the multitude of possible states of interaction between the factors that define a specific training tool. As the MPTF is theoretically-grounded in RLD principles, it is intended to assess and demonstrate the direct applicability of these principles to MPT approaches.

The y-axis addresses the perceptual function being targeted by the training (i.e. 'what' is being trained). It assesses whether the training targets a perceptual skill ranging from low-order visual skills to high-order perceptual-cognitive skills. Distributing targeted skills across the continuum, generalised visual skills (e.g. acuity, contrast sensitivity, accommodation, vergence<sup>2</sup>) cluster at one end of the continuum, and sport-specific anticipation<sup>54</sup> and decision-making<sup>3</sup> skills sit at the other. Between these extremities lies functions/skills that gradually increase in their sport-specificity: eye-hand/-foot coordination,<sup>2</sup> general then sport-specific visual attention factors,<sup>57</sup> QE,<sup>40</sup> sport-specific pattern recognition, and situational probabilities, kinematic and contextual information recognition skills.<sup>3</sup> While we are unable here to provide a detailed account of expert-novice differences in these targeted skills, reviews generally indicate inconsistent/moderate differences for visual skills and more consistent support for perceptual-cognitive skills.<sup>4,8,9</sup> This general finding implies that using MPT tools that target perceptual-cognitive skills may be more beneficial for improving sport performance, however, further research investigating expert-novice differences in the various perceptual skills using MPT tools as a baseline testing tool needs to be accumulated. Based on existing evidence, the MPTF predicts that the effectiveness of MPT will increase as the specific perceptual function progresses towards a sport-specific perceptual-cognitive skill.

The x-axis addresses how similar the stimuli presented during the MPT approach is with that encountered during competition (i.e. the training stimuli's degree of correspondence). It assesses whether a MPT tool uses generic (e.g. alpha-numeric) through to sport-specific (e.g. opponents, teammates) training stimuli. The MPTF simultaneously considers two factors that may mediate their overall correspondence: *visual correspondence*, describing the similarity in the stimuli's visual appearance (e.g. a tennis ball versus a yellow dot/sphere), and *behavioural correspondence*, describing the similarity in the stimuli's movement characteristics (e.g. trajectory). Tasks that contain generic stimuli (low visual correspondence) fall within the left-hand sector (Fig. 2(a)), and tasks that contain sport-based stimuli (high visual correspon-



**Fig. 1.** Schematic design of the theoretically-grounded MPTF that hypothesises the predicted transfer effect of MPT tools on competitive performance. The MPTF's volumetric space, created by three continua, captures the possible states of interaction between the three key MPT design factors that may influence their effect on improving performance; *targeted perceptual function* (y-axis, low-order to high-order), *stimulus correspondence* (x-axis, generic to sport-specific) and *response correspondence* (z-axis, generic to sport-specific). Increasing stimulus correspondence, conveyed by small left-hand arrowheads and large right-hand arrowheads on the x-axis, resets at the origin allowing generic stimuli with high behavioural correspondence to be distinguished from sport-based stimuli with low behavioural correspondence. The MPTF's key hypothesis is indicated by the expanding double-broken arrow — as each factor approaches maximal correspondence with its function and existence in competitive sport environments, MPT should provide stronger transfer effects.



**Fig. 2.** Approximated schematic plot of exemplar MPT tools overlaid on the MPTF. For clarity, the MPTF has been divided based on stimulus correspondence; part (a) portrays all MPT tools comprised of generic (low visual correspondence) stimuli, part (b) portrays all MPT tools comprised of sport-based (high visual correspondence) stimuli. The z-axis gridlines have been labelled according to the different classifications of MPT response modes. MPT tools/approaches portrayed as a region indicate that within the one approach, depending on the region's directional characteristic, either multiple perceptual skills may be targeted and/or multiple stimulus types and/or response modes may be used.



dence) are positioned within the right-hand sector (Fig. 2(b)) and are further distinguished by their behavioural correspondence. For example, generic stimuli used in NeuroTracker<sup>53</sup> and point-light displays<sup>55</sup> are visually similar (dots moving onscreen) but can be differentiated by their behaviour (random vs. structured movement). Additionally, EyeGym<sup>46</sup> and VR,<sup>21</sup> which both use computer-generated sport-based stimuli, can be differentiated because the stimuli behaviour in EyeGym is unstructured (non-sport specific), whereas VR stimuli display more highly structured (sport-specific) behavioural patterns. According to RLD, creating training tasks that accurately sample information from the competitive environment is critical for maximising transfer.<sup>11</sup> For example, cricket batsmen's movement patterns have been shown to change when performing against different perceptual information variables provided by a 'live' bowler (i.e. high visual and behavioural correspondence) versus a bowling machine (low visual and behavioural correspondence).<sup>58</sup> It follows that the MPTF predicts that tasks which incorporate sport-specific stimuli (higher visual and behavioural correspondence) will facilitate stronger transfer than tasks composed of generic stimuli.

The z-axis addresses how similar the primary type of response required when performing MPT is to the typical natural skill execution performed during competition (i.e. the training response's degree of correspondence). It assesses whether a MPT uses generic (e.g. verbalised or written responses) or sport-specific (e.g. natural skill performance) responses. A distribution of responses could include: dissociated responses (e.g. verbal/written reports, button/key press, fine ocular adjustments), non-specific gestures (e.g. reach-and-touch, generic movement coordination), simulated actions (e.g. racquet swing simulation), and sport-specific actions (e.g. natural skill execution) (Fig. 2). To align these with specific MPT approaches, the MPTF positions video-/image-based PCT tasks requiring verbal<sup>25</sup> or button press<sup>18,19</sup> responses at the continuum's base, closely followed by SVT requiring fine ocular adjustments<sup>2</sup> and vision-based 'apps',<sup>46</sup> visual-perceptual tasks requiring coordinated reach-and-touch responses,<sup>52</sup> video-/image-based PCT,<sup>6,7</sup> VR,<sup>21</sup> and field-based tasks.<sup>5</sup> Sustaining perception-action links by responding with movement may enhance the accuracy of perceptual-cognitive performance, compared to verbalised responses,<sup>59</sup> and increasing the specificity of a response (i.e. more complete skill execution, high response correspondence) leads to better performance.<sup>60</sup> Further, transfer may be best facilitated by ensuring that perceptual processes are calibrated to existing action capabilities, suggesting the movement response (action), if incorporated, should still be achievable.<sup>17</sup> Given the emphasis that RLD places on achieving *action fidelity*<sup>11,13</sup> (i.e. the similarity between a performer's movement behaviour in training and competition contexts) in training tasks, the MPTF predicts that transfer effects will occur if the MPT task incorporates more sport-specific responses.

#### 4. Future applications of the MPTF

In summary, the MPTF provides testable predictions that transfer will be maximised in training tasks where the perceptual function targeted in training, the training stimuli and the response type demonstrate maximal correspondence to the competition environment. The MPTF offers significant benefits in empirical and applied settings because it addresses the range of MPT approaches available, and makes predictions about the effectiveness of those approaches for future research to address. A meta-analysis guided by the MPTF could be used to demonstrate which tools, or MPTF regions, are effective or require more comprehensive investigation to support their utility, and how best to implement MPT tools to obtain a performance benefit. The MPTF can also guide the design

of future research, which should use representative transfer tests to compare the effectiveness of various MPT tools for a given sport or athlete cohort. By further enhancing understanding of how the design factors interact, MPT tools that specifically address each factor can be created and implemented in sport. As empirical evidence accumulates the MPTF can become a reference tool to assist practitioners in explaining the value of available MPT tools with coaches to help guide decisions about which approach(es) to use.

#### 5. Conclusion

A theoretically-grounded framework that makes testable predictions about a given MPT approach's effect on performance is crucial for guiding the selection and implementation of effective MPT tools in sport. The MPTF captures the scope of training approaches that specifically aim (or claim) to improve sport performance by identifying three interacting design factors that are likely to influence the capacity of a MPT tool to achieve this aim. The MPTF's key prediction is that stronger transfer effects will be evident by using a MPT approach that demonstrates maximal training-to-competition correspondence between the specific perceptual skill being trained, the stimuli used to train that skill, and the type of response required during the training task. This prediction needs to be robustly assessed in future research that incorporates well designed representative transfer tests, with the MPTF having the flexibility to be adjusted as this additional evidence is accumulated. Once this is achieved, the MPTF can serve as a guide when selecting a MPT tool for a particular sport or athlete(s).

#### Practical implications

- The MPTF forms testable hypotheses regarding the comparative effectiveness of various MPT tools, based on key features of task design, which has broad future application when seeking to empirically establish the utility of a tool(s) in a given sport.
- This knowledge then has applied impact, where the MPTF can be used as coach-scientist discussion point, and act as a guide when selecting and implementing effective MPT programs in to a sports training program.

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